



CH04/990

18 • OCT 2004 (18 • 10 • 2004)



INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

REC'D 02 NOV 2004

WIPO

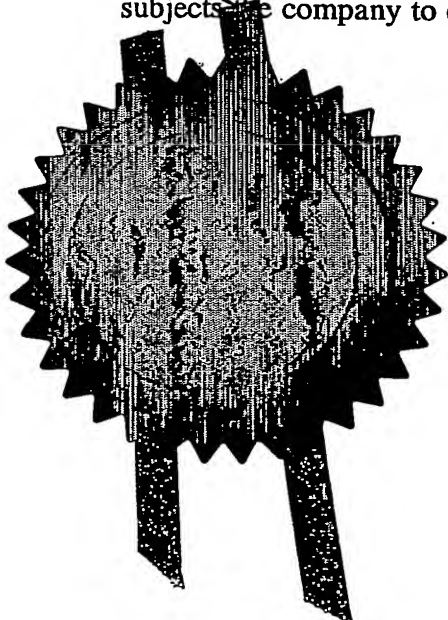
PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.



Signed

AT Evans

Dated

14 September 2004

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN
COMPLIANCE WITH
RULE 17.1(a) OR (b)

BEST AVAILABLE COPY

Patents Act 1977
(Rule 16)

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office which you fill in this form)



The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference

EH/TC/58313

2. Patent application number

(The Patent Office will fill in this part)

28AUG03 E833113-2 C03008

P01/7700 0.00-0320067.2

0320067.2

27 AUG 2003

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Ron Shu-Yuen HUI
2B, Block 29
Greenwood Terrace
26-28 Sui Wo Road
Shatin, New Territories
HONG KONG

Henry Shu Hung CHUNG
Flat A, 19/F Tower 1
Scenecliff
33 Conduit Road
HONG KONG

Patents ADP number (if you know it)

8664690001

8700882001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

Apparatus and Method for Providing Dimming Control of Lamps and Electrical Lighting Systems

5. Name of your agent (if you have one)

LLOYD WISE

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Commonwealth House
1-19 New Oxford Street
London WC1A 1LW

Patents ADP number (if you know it)

117001 ✓

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these

Country

Priority application number
(if you know it)

Date of filing
(day / month / year)

earlier applications (and if you know it) the or each application number

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

date of filing
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request (Answer 'Yes' if:

NO

a) any applicant named in part 3 is not an inventor, or

b) there is an inventor who is not named as an applicant, or

c) any named applicant is a corporate body.

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form.
Do not count copies of the same document

Continuation sheets of this form

Description 16

Claim(s) 5

Abstract 1

Drawing(s) 11

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translation of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77) 1

Request for substantive examination (Patents Form 10/77)

Any other documents
(please specify)

11.

I/We request the grant of a patent on the basis of this application.

Signature

Date:

27 August 2003

LLOYD WISE

12. Name and daytime telephone number of person to contact in the United Kingdom

Esmond A Hitchcock 020-7571-6200

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered 'Yes' Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) For details of the fee and ways to pay, please contact the Patent Office.

DUPLICATE

APPARATUS AND METHOD FOR PROVIDING DIMMING
CONTROL OF LAMPS AND ELECTRICAL LIGHTING SYSTEMS

5

FIELD OF THE INVENTION

This invention relates to apparatus and methods for providing dimming control of individual electrical lamps or more generally electrical lighting systems including systems formed of a plurality of individual lamps. The invention relates in particular to a simple general purpose and non-intrusive dimming system that can be retro-fitted to
10 existing lamps and which is non-intrusive in the sense that when not in use the dimming apparatus has no effect on the normal operation of the lamp.

BACKGROUND OF THE INVENTION

A wide range of different types of lamps and lighting systems are used in various
15 different applications. These include fluorescent lamps, high energy discharge lamps and gaseous discharge lamps. A general drawback to such lamps, however, is that in general terms they are considered to be "non-dimmable", that is to say they tend to have a fixed power output and are of a certain defined brightness and intensity. Generally speaking this is not desirable because the light can often be too bright and harsh, and can be
20 wasteful on power.

For both aesthetic and energy conservation reasons, therefore, various attempts have been made in the prior art to provide such lamps with a dimming control capability so that the brightness of the lamps can be adjusted.

25

PRIOR ART

Existing dimming methods for existing lighting systems include Triac-based dimmers for incandescent lamps and gaseous discharge lamps compatible with triac dimmers, dimmable electronic ballasts for discharge lamps, and a range of disparate techniques for dimming lamps driven by magnetic ballasts. These prior art techniques
30 will be discussed in turn.

Edison-type incandescent lamps have been used for a long time. Incandescent lamps do not have an in-built dimming capability and in order to control the light intensity of the incandescent lamps, triac dimmers have been used as the dimming devices as illustrated in Fig.1(a). A triac dimmer conventionally consists of two thyristors connected in anti-parallel configuration and also a triggering circuit which can control the delay angle for turning on the appropriate thyristor in the relevant half-cycle of the mains voltage. As shown in Fig.1(b), by controlling the delay firing angle (α), the voltage content of the mains voltage can be controlled as the output voltage of the triac dimmer and applied to the incandescent lamp and some triac-compatible compact fluorescent lamps (CFL). However, because the mains input current through the triac dimmer is affected by the shape of the triac dimmer's output voltage, when the delay firing angle is not zero the input current will deviate from the sinusoidal shape of the mains voltage, resulting in power line harmonics. This high current harmonic content is an inherent problem of lighting systems controlled by triac dimmers, especially when the delay angle is large.

Fig.1(c) shows a power flow diagram in the triac-dimmer controlled lighting system. The triac dimmer circuit has to handle both the real power (P) and the reactive power (Q) of the lighting devices or systems. Thus, its voltage-current (VI) ratings must be large enough to handle the full power of the lighting systems. Two examples of triac based dimmers are described in US4,437,043 and US5,757,145.

Recently, there has been an increasing trend of using dimmable electronic ballasts for discharge lamps such as fluorescent lamps and high-intensity-discharge (HID) lamps. The schematic of dimmable electronic ballasts for discharge lamps is shown in Fig.2. A dimmable electronic ballast usually has a 4-wired connection arrangement on the input side. Two connections are for the "live" and "neutral" of the ac mains, the other two are for the DC dimming level control signal, which is normally set to be within 1V to 10V.

A dimmable electronic ballast is essentially a power converter that controls the power flow to the lamps. Conventional dimmable electronic ballasts dim the lamp by increasing the switching frequency of the ballast inverter. The impedance of the inductor that limits the current to the lamp will increase with operating frequency, and thus the lamp power can be controlled by controlling the inverter frequency.

As with a triac dimmer, a dimmable electronic ballast is conventionally connected between the ac mains voltage and the lighting load. Thus, existing dimmable electronic ballasts have to handle the full power (both real power P and reactive power Q) of the lighting load. The power capability of the ballast must therefore be higher than sum of the full lamp power and the electronic loss.

As shown in Fig.1(c) and Fig.2, the power flow diagrams indicate that existing dimming devices or circuits need to handle both the real power and the reactive power. It is therefore not economical to use a single dimming device based on these methods to dim a lighting system formed of a large group or network of lamps. A triac dimmer is typically limited to a few hundreds of watts and dimmable electronic ballasts are usually designed for one or a pair of discharge lamps only.

Magnetic ballasts have a longer history than electronic ballasts. They have been used widely for both fluorescent lamps and high intensity discharge (HID) lamps. Unlike electronic ballasts that operate at high frequency ($>40\text{kHz}$ typically), magnetic ballasts operate at the mains frequency (50Hz or 60Hz).

Magnetic ballasts have several advantages over electronic ballasts. These advantages include extremely high reliability and long lifetime (>15 years typically without replacement), robustness against transient voltage surge (e.g. due to lightning) and hostile working environment (e.g. high humidity and temperature). In particular, magnetic ballasts offer superior lamp-arc stability performance in HID lamps, which have a well-known problem of acoustic resonance when the HID lamps are operated with high-frequency electronic ballasts. This is the reason why HID lamps market is dominated by magnetic ballasts, which operate at mains frequency and will not trigger acoustic resonance in the HID lamp arc.

The major limitation of most of the magnetic ballasts is their inability to dim the discharge lamps. Several techniques have been reported to try and get round this problem and to provide dimming magnetic ballasts.

One prior proposal involves tapping the ac mains transformer to achieve a magnitude change in the mains voltage. Theoretically, discharge lamps driven by magnetic ballasts can still be dimmed by manually tapping the mains transformer in order to reduce the mains voltage. However, this is a mechanical solution and is not a suitable

dimming solution, particularly when the dimming process must be centrally or automatically controlled. US6,271,635 describes the use of a two-windings autotransformer for achieving a 2-level dimming system for discharge lamps. The two windings provide two separate voltage sources. A switch is used to choose either the voltage from one set of winding or the full voltage from two sets of windings connected in series. Such 2-level dimming system can be used for a plurality of lamps, but the dimming level is discrete and is not continuous. Persson et al ("A performance comparison of electronic vs. magnetic ballast for power gas-discharge UV lamps", Rad Tech' 98, Chicago, pages 1 to 9, 1998) proposed a multilevel dimming system using a more complicated transformer.

Another possibility is the use of an external current-control power circuit for controlling the current into the magnetic ballast - discharge lamp system. US6,538,395 and US6,121,734 disclose the use of an external current-control power circuit that controls the magnitude of the input current to the magnetic ballast driven discharge lamp system. Such an approach controls the lamp power by varying the magnitude of the input current at mains frequency. However, the current-control power stage still has to handle both real and reactive power of the lighting load.

Alternatively, an ac-ac converter such as a cycloconverter (Fig.3) can in principle be used to create a mains-frequency ac voltage with controllable magnitude to the lighting load consisting of both ballast and lamp. One practical ac-ac voltage converter (US4,350,935) uses a power converter to chop the AC sinusoidal voltage into voltage pulses with the sinusoidal envelope. However, the ac-ac voltage converter approach (including the use of a cycloconverter and the converter in US4,350,935) does not generate a sinusoidal voltage for the lighting load. Consequently, lots of current harmonics will be generated in the process, leading to harmonic pollution problems in the power lines. In addition, the power flow representation in Fig.3 shows that such an approach also requires the ac-ac voltage converter to handle both the real and reactive power. The power rating of the power converter must therefore be higher than the full power of the lighting load.

Several techniques have been reported for dimming magnetic ballasts by varying the impedance in the magnetic ballast system. US5,389,857 discloses the use of a 2-step

inductor as the choke in the magnetic ballast. The 2-step inductor consists of two inductors connected in series. With a switch that can by pass one of the two inductors, the inductance of the 2-step inductor can be altered in a discrete manner. The shortcoming of this approach is that continuous dimming levels cannot be achieved.

5 US5,432,406 describes the use of a saturable reactor (inductor) in the magnetic ballast that can be dimmed continuously within a limited range. By adding an extra winding to the reactor and injecting a dc current into this extra winding, the magnetic core of the reactor can be saturated. Therefore, the impedance of the inductor in the magnetic ballast can be changed and the lamp current can be altered. However, this
10 method cannot be applied as a general-purpose dimming method to existing magnetic ballasts that have not got the saturable reactor.

US5,949,196 describes the use of a current draining capacitor for dimming purpose in discharge lamp systems. A switchable capacitor is connected across a discharge lamp. If dimming is required, the capacitor is switched on so that some lamp
15 current will be diverted away from the lamp into the capacitor. In this way, the lamp current and hence the lamp power and lighting intensity can be controlled in a discrete manner. However, continuous dimming levels cannot be achieved in this method.

In the fluorescent lamps (low-pressure discharge lamps) market, electronic ballasts are replacing traditional non-dimmable magnetic ballasts. Operating at high
20 frequency (typically above 20-kHz) electronic ballasts can eliminate the flickering effects of the fluorescent lamps and achieve a higher efficacy than mains-frequency (50Hz or 60Hz) operated magnetic ballasts. Therefore fluorescent lamps driven by electronic ballasts consume less energy for the same light output when compared with lamps driven by magnetic ballasts. However, one major weakness of electronic ballasts is the relatively
25 short lifetime. Magnetic ballasts can normally operate over 10 years without replacement and it is rare to have electronic ballasts with such long lifetime. If magnetic ballasts can be made dimmable, the combined features of their long lifetime, high reliability and energy saving can make such "dimmable magnetic ballasts" an attractive solution to low-pressure discharge lamps such as fluorescent lamps.

30 In the high-pressure lamps such as the high-intensity-discharge (HID) lamp market, magnetic ballasts are still considered to be a more reliable option than electronic

ballasts. The reason for this is that HID lamps could suffer from acoustic resonance when they are operated at frequency higher than 1kHz. Acoustic resonance is due to the power pressure variation in the lamp tube that could trigger various forms of resonance. In order to avoid acoustic resonance, HID lamps are usually operated at low frequency (less than 1 kHz) or very high frequency ($> 350\text{kHz}$ - 700kHz). Although some electronic ballasts are being promoted for use with HID lamps, the lamp characteristics change with time and thus lamp stability is not guaranteed when the lamp's ageing effects become significant. Despite the increasing efforts in developing electronic ballasts for HID lamps, magnetic ballasts still dominate the HID lamp market because of their extremely high lamp arc stability, high ballast reliability and low cost. Particularly in the outdoor lighting applications (such as street lamps) in which robustness and high reliability against lightning are important criteria for consideration.

SUMMARY OF THE INVENTION

According to the present invention there is provided apparatus for providing dimming control of an electrical lamp of the type driven by a ballast that is provided between an AC mains supply and the lamp, comprising means located in series between the mains supply and the ballast for inserting an auxiliary voltage, said auxiliary voltage being out of phase with said mains supply, whereby the supply voltage is the vectorial combination of the voltage applied to the ballast and the auxiliary voltage, whereby the voltage applied to the ballast has a magnitude that is smaller than the magnitude of the voltage of the mains supply, and further comprising means for controlling the auxiliary voltage for varying the voltage applied to the lamp.

In a preferred embodiment the auxiliary voltage is maintained at 90 or 270 degrees out of phase with the current flowing through said apparatus, and wherein only the magnitude of the auxiliary voltage is used for varying the voltage applied to the lamp. This is advantageous because it ensures that the dimming control apparatus handles only the reactive power, which minimizes real power loss in the dimming control apparatus.

In one preferred embodiment the apparatus comprises a half-bridge inverter including two switches that are switched at high-frequency to generate a pulse-width-modulated (PWM) waveform as an output. Preferably the PWM output of said half-

bridge inverter is filtered to provide an auxiliary voltage of a highly sinusoidal character. In this embodiment means are provided to select a desired the DC link voltage for the half-bridge inverter in order to control the magnitude of the auxiliary voltage. In particular means are provided to maintain said DC link voltage at said desired value and to maintain the phase of said auxiliary voltage 90 or 270 degrees out of phase with the current flowing through said apparatus. For example a closed loop control scheme may be used for maintaining said DC link voltage at said desired value and for maintaining the phase of said auxiliary voltage 90 or 270 degrees out of phase with said current.

Preferably switch means are provided whereby the apparatus may be by-passed if dimming control is not required and the voltage of the mains supply is applied directly to the ballast.

Viewed from another aspect the present invention provides an electrical lighting system comprising at least one lamp connected to an AC mains supply through a ballast, said system further comprising means for providing dimming control of said at least one lamp, said dimming control means comprising means located in series between the mains supply and the ballast for inserting an auxiliary voltage, said auxiliary voltage being out of phase with said mains supply, whereby the supply voltage vectorial combination of the voltage applied to the ballast and the auxiliary voltage, whereby the magnitude of the voltage that is applied to the ballast is smaller than the magnitude of the voltage of the mains supply, and further comprising means for controlling the auxiliary voltage for varying the voltage applied to the lamp.

Viewed from a still further aspect the invention also provides a method for providing dimming control of an electrical lamp driven by a ballast, comprising inserting an auxiliary voltage between an AC supply and said ballast, said auxiliary voltage being out of phase with the voltage of said AC supply whereby the supply voltage is the vectorial combination of the voltage applied to the ballast and the auxiliary voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:-

Figs.1(a)-(c) illustrate the operation of a prior art triac based dimmer,

Fig.2 is a block diagram illustrating a conventional dimmable electronic ballast,
Fig.3 is a block diagram illustrating the use of an ac-ac converter for dimming
control of a magnetic ballast system according to the prior art,
Figs.4(a)-(c) show apparatus according to an embodiment of the invention and in
particular comprise (a) a block diagram, (b) a schematic illustrating a group pf
loads and showing power flow, and (c) the equivalent circuit,
Figs.5(a) and (b) are vector diagrams of a discharge lamp system driven by a
magnetic ballast (a) without using the dimming control apparatus of the present
invention, and (b) with use of dimming control,
Fig.6 is a schematic diagram showing the power electronic circuit of a dimming
control apparatus according to an embodiment of the invention,
Fig.7 illustrates a closed-loop control system for use in an embodiment of the
present invention,
Fig.8 is a block diagram illustrating an experimental set-up,
Figs.9(a)-(f) show experimental results,
Figs.10(a) and (b) show measurements of (a) real power consumption of the load
against voltage in one experimental example,
Figs.11(a) and (b) show measurements of (a) real power consumption of the load
against voltage in another experimental example, and (b) total power loss in the
dimming control apparatus,
Fig.12 shows an alternative embodiment that uses a full-bridge inverter to
generate the auxiliary voltage, and
Fig.13 shows an alternative embodiment in which a separate energy source is
used for the auxiliary voltage.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention, at least in its preferred forms, provides a highly energy-efficient and non-intrusive dimming method and apparatus for electric lighting systems such as fluorescent and HID discharge lamps powered either by magnetic ballasts or by some electronic ballasts. This method and apparatus can turn existing "non-dimmable" magnetic ballasts - lamp systems into "dimmable" ones with real energy saving. The

proposed dimming method achieves the dimming function with a real energy saving by controlling the voltage available to the ballast-lamp system without handling the real power of the lighting system. The concept behind the invention is a new integrated voltage-vector control and reactive-power control concept.

- 5 As will be understood from the detailed description to follow, by controlling the reactive power flow to the lighting system, the proposed dimming apparatus inserts a controllable voltage vector to the mains voltage. The resultant voltage available to the ballast - lamp system can thus be controlled. In a preferred embodiment the dimming method and apparatus achieves minimum power loss by handling only reactive power.
- 10 Therefore, the power rating of the proposed dimming device can be much smaller than the full power rating of the lighting system. This enables the proposed dimming device to dim a high-power lighting systems or a group of lighting devices. Another advantage of the invention its non-intrusive nature. The ballast-lamp system can still function at full power (ie a non-dimming condition) normally even if the proposed dimming apparatus is
- 15 not operating.

The proposed method and apparatus can be used to dim individual discharge lamps or a network of HID lamps such as street lamps. It can be used for both indoor and outdoor applications.

- Fig.4(a) shows the basic concept of the integrated voltage-vector control and reactive-power control concept in an embodiment of the invention. In order to dim the
- 20 lighting system, the ac voltage available to the lighting load is varied without the need for processing the real power of the lighting load. V_s is ac mains voltage vector; V_a is auxiliary voltage vector inserted by the dimming device and V_L is the resultant voltage vector for the load. I_a is the current vector of the dimming device and is kept perpendicular to the auxiliary voltage (ie it is 90 or 270 degrees out of phase with V_a). I_L is the load current and is equal to I_a .
- 25

- The power flow diagram of an embodiment of the invention is shown in Fig.4(b). By inserting an auxiliary voltage vector V_a through the use of a reactive-power control circuit, the resultant voltage V_L , which is the vectorial difference of the supply voltage vector V_s and the auxiliary voltage vector V_a , can be controlled. Because the generation of V_a is done by dealing with the reactive power Q , the dimming device theoretically
- 30

does not handle any real power P of the lighting load. The only practical loss in the dimming device is the conduction loss and switching loss in the power circuitry of the dimming device. As shown later in the measurements of a number of experimental examples, the total loss of the dimming device is typically less than 10% of the saved lamp power in the dimming process. For example, if the lamp power of 150W in a discharge lamp is dimmed to 80W, the lamp power reduction is 70W and the dimming device will consume less than 7W. Consequently, a real energy saving of 63W is achieved in this example.

Fig.4(c) shows the equivalent circuit of an embodiment of the invention. Based on the power network theory, V_x is a controlled ac voltage source on the transmission end of the transmission network. This V_x is equivalent to the ac voltage (generated by the inverter bridge) before being filtered by the filter inductor L_f . The auxiliary voltage V_a (the filtered version of V_x) is on the receiving end of the network. The magnitude and phase shift δ of V_x is controllable.

The real power P and the reactive power Q supplied to the circuit can be shown to be:

$$P = \frac{V_a V_x}{\omega L_f} \sin \delta \quad (1)$$

$$Q = \frac{V_x^2}{\omega L_f} - \frac{V_a V_x}{\omega L_f} \cos \delta \quad (2)$$

where $\omega = 2\pi f$, f is the mains frequency, and δ is the angle between the voltage vectors V_a and V_x .

From Equations (1) and (2) it can be seen how the voltage-vector generation and reactive-power control concept minimizes power loss in the dimming circuit. Equation (1) indicates that, by keeping δ zero, $\sin \delta$ is zero and this P is equal to zero. So the dimming circuit will not consume real power of the power flow. Equation (2) shows that reactive power Q and the auxiliary voltage vector V_a can be adjusted by controlling the

magnitude of V_x . The magnitude of V_x can be controlled by regulating the dc link voltage V_{dc} of the inverter bridge in a closed-loop control scheme as will be explained further below.

5 Preferably, as will be described below, a voltage source inverter with a half bridge configuration is used in this embodiment of the invention with its dc side being supplied from two capacitors. The capacitor voltage can be varied by adjusting δ . If δ is positive, the capacitor voltage will be increased, and vice versa. This achieves the function of reactive power and voltage control.

10 Fig.5(a) shows a typical vector diagram of a magnetic ballast driven discharge lamp system without any dimming function (Vectors are assumed to rotate in the anticlockwise direction at the mains frequency.). In this case, V_s is simply equal to V_L . Because the magnetic ballast consists of a large inductor or choke and the lamp arc can be represented as a resistance, the circuit is highly inductive. Thus, the load current I_L lags behind the supply voltage V_s by a phase angle ϕ . Fig.5(b) shows the vector diagram
15 if the dimming device of an embodiment of the present invention is included. The dimming device inserts (without dissipating a lot of power) a voltage vector V_a to the system. The resultant load voltage available to the lighting system can be altered (made smaller) smoothly. As a result, the lamp power can be controlled by the voltage-vector concept. Comparing Fig.5(a) (without dimming device) and Fig.5(b) (with dimming
20 device), the insertion of an auxiliary voltage vector V_a to the mains voltage vector V_s can reduce the magnitude of the resultant voltage V_L . Hence, the magnetic ballast driven lighting system will have less current I_L and the lamp power can be reduced.

I_a and the load current I_L are identical in Fig.5(b). From a consideration of Fig.5(b) it can be seen that in principle the magnitude of the voltage applied to the load could be
25 controlled by varying the magnitude and/or phase of the auxiliary voltage. However, it is greatly preferable to maintain the phase of the auxiliary voltage so as to be perpendicular to the phase of the current in order to minimize the power loss in the dimming device, therefore the current vector entering the dimming device ($I_a = I_L$) should preferably be kept 90 or 270 degrees out of phase with the auxiliary voltage vector (V_a) generated by
30 the dimming device. As the vectors I_a and V_a are perpendicular to each other, the dimming device theoretically consumes no real power. In practice, the dimming device

will consumes a very small amount of power due to conduction loss, switching loss and magnetic loss in the dimming-device. But the total power loss in the dimming device is only a small fraction (typically less than 10%) of the total saved lamp power.

Fig.6 shows the schematic of the power electronic circuit of a dimming device according to an embodiment of the invention. The device includes a by-pass switch S_m (e.g. an electro-mechanical switch such as a relay or a contactor) that is "normally closed" (N.C.) when the dimming circuit is not activated. Under this inactive operating mode (when the relay is closed), I_a bypasses the dimming circuit and V_a is zero. Thus, the proposed dimming device is non-intrusive to the electric lighting system to be dimmed. When the dimming device is activated, S_m is opened and I_a will flow into the dimming circuit.

The circuit of the dimming device of this embodiment consists of a half inverter bridge with a pair of totem pole power electronic switches S_1 and S_2 . The two capacitors (C_1 and C_2) serve as dc link bulk capacitors and energy storage capacitors. Through the two freewheeling diodes D_1 and D_2 and the switching actions of S_1 and S_2 , DC voltage can be built up in the two series connected capacitors C_1 and C_2 , when the dimming device is activated. The DC voltage across C_1 and C_2 provides a DC voltage source for the half inverter bridge. The two power electronic switches S_1 and S_2 in the half inverter bridge are high-frequency switched under a sinusoidal pulse-width-modulated (PWM) scheme in order to generate a PWM voltage waveform with a high-quality sinusoidal content. The PWM voltage waveform is then filtered by a low-pass filter comprising an inductor L and a capacitor C so that the high-frequency voltage harmonics in the PWM voltage waveform are filtered. The filtered voltage is then a high-quality sinusoidal voltage, which is the auxiliary voltage V_a generated by the dimming device.

It should be noted that a full-bridge inverter can also be used to replace the half-bridge inverter as shown in Fig.12. However, a half-bridge inverter uses half of the number of power electronic devices of the full-bridge counterpart and is therefore a more cost-effective solution.

When activated, the dimming circuit starts its operation by opening the normally closed bypass switch S_m . The dimming level of the lighting load can be regulated using a closed-loop control scheme. The dimming level can be determined by setting a reference

level for the DC link voltage (V_{dc}) of the half-bridge inverter. If this V_{dc} reference is set at zero, for example, the magnitude of the V_a generated by the dimming circuit will be zero. If the V_{dc} reference is set at a certain level, then this V_{dc} will be the dc link voltage for the inverter and will affect the magnitude of the auxiliary voltage V_a .

5 The PWM voltage generated by half-bridge inverter will have a peak-to-peak magnitude of $+0.5V_{dc}$ and $-0.5V_{dc}$. In the closed-loop control, the phase angle between the mains voltage V_s and the auxiliary voltage vector V_a will be controlled in such a way that (1) the actual dc link voltage V_{dc} will be regulated according to its reference setting and (2) $I_a (=I_L)$ will be 90 or 270 degrees out of phase of V_a . Condition (1) determines
10 the magnitude of V_a . Condition (2) makes sure that the dimming circuit only handles reactive power (Q) of the lighting system. In this way, the power rating of the dimming circuit can be much smaller than that of the lighting system. Consequently, low-cost dimming circuit can be developed for dimming "non-dimmable" lighting system.

Fig.7 shows a block diagram of the voltage-vector and reactive-power control
15 scheme for the dimming device. As discussed with reference to Fig.6 a normally-closed (N.C.) electro-mechanical switch (typically a relay or a contactor) is used as a bypass switch if the dimming circuit is not activated. Once the dimming circuit is activated, the N.C. switch will be connected to the circuit as shown in Fig.7. One sensor (typically a signal transformer) is used to sense the mains voltage so that the phase of V_s can be
20 obtained. Another sensor is a dc voltage sensor (typically a potential divider) for detecting the dc link voltage V_{dc} of the inverter-bridge in the dimming circuit. The dimming control is controlled in the form of a dc voltage (V_{dc}) reference. A comparator is used to derive the error signal between the V_{dc} reference and the V_{dc} feedback signal. The error signal is fed to an error compensator or typically a proportional-integral (PI)
25 controller, which generates a phase shift signal. With the phase shift signal and the phase reference of the mains voltage as inputs, a phase locked loop is used to generate pulse-width-modulated (PWM) gating signals to the power switches S_1 and S_2 so that the auxiliary voltage vector V_a will have appropriate phase shift with the mains voltage vector V_s in order to keep the dc link voltage V_{dc} at the V_{dc} reference level. By keeping
30 V_{dc} at the required reference level, there is no net real power consumption in the dimming circuit. Hence, this control scheme has the automatic feature that the auxiliary

voltage vector V_a is perpendicular to the input current I_a of the dimming circuit. In other words, the proposed control scheme ensures that the dimming circuit generates the required auxiliary voltage vector by handling reactive power only. The power ratings of the dimming circuit can therefore be designed according to the reactive power of the lighting load and not the full power of the lighting load.

The proposed dimming method and apparatus has been tested with an experimental prototype and several discharge lamps driven by magnetic ballasts have been successfully dimmed. Fig.8 shows the block diagram of the experimental setup. For a range of discharge lamps, the dimming device is connected to the magnetic ballast – discharge lamp system as shown in Fig.6.

Tests were carried out to confirm the new dimming concept. By increasing the reference setting for V_{dc} , the dc link voltage is regulated to different levels in order to generate an auxiliary voltage V_a . The mains voltage was 220V at 50Hz. The mains voltage V_s , auxiliary voltage V_a , the resultant voltage (V_{Load}) available to the lighting load, and the load current I_L (same as I_a) were measured. The total input power (P_{Load}) consumed by the lighting load and the total power loss in the new dimming device were also measured.

Figs.9(a)-(e) show the measurements of a 150W high-pressure sodium discharge lamp driven by a magnetic ballast. This system was dimmed by the new dimming device.

Fig.9(a) shows the measured V_s , I_a , V_a and V_{Load} (V_L) when the bypass relay switch S_m is normally closed and the dimming circuit is not activated. The lamp operates at full power and it can be seen that V_{Load} is equal to V_s , and V_a is zero because S_m is closed.

Fig.9(b) shows the measurements when the bypass relay is opened and the dimming circuit is activated with a very small (almost zero) dimming setting. It can be observed that V_a is only 7V and that V_s is almost the same as V_{Load} . The lamp operates almost at full power.

Fig.9(c) shows the measurements when the sodium discharge lamp is dimmed to about 75% of the full power. The auxiliary voltage is about 20V and V_{Load} is now 198V. Compared with the load current I_a in Fig.9(a) and Fig.9(b), the load current I_a in Fig.9(c) is reduced, confirming the reduction of the lamp power and the proposed dimming

principle. It is important to note from Fig.9(c) that V_a and I_a are 90 degrees out of phase with each other, confirming that the dimming circuit essentially handles only reactive power. Test results for the lamp power dimmed down to 50% and 30% of the full lamp power are recorded in Fig.9(d) and Fig.9(e), respectively.

5 From Figs.9(a)-(e) it is clearly demonstrated that (i) a voltage vector V_a with increasing magnitude can reduce the resultant voltage V_{Load} for the lighting load and (ii) V_a and I_a can be kept out of phase by 90 degrees. Fig.9(f) shows the measurements of the actual real power consumption (P) of the lighting load (including both magnetic ballast and the sodium discharge lamp). The integrated voltage-vector control and reactive-
10 power control concept for dimming purposes is practically confirmed and demonstrated.

A Philips Mastercolour (CDM-T 150W/830) 150W metal-halide lamp was also tested with the new dimming device. The Philips 150W Metal-Halide lamp is driven by a Philips (BSN 150L 407 1 TS) magnetic ballast. Fig.10(a) shows the measurements of the real power consumption of the lighting load over a dimming range. The real power loss
15 dissipated in the new dimming device over the same dimming range was recorded and plotted in Fig.10(b). When the lamp power is reduced from 150W to about 92W (i.e. a power saving of 58W), the dimming device consumes only less than 6W. This results in a real power saving of 52W. In other words, the dimming device consumes only about 10% of the saved lamp power.

20 The results based on the 150W Sodium discharge lamp and 150W Metal-Halide lamp confirm that at least in preferred embodiments the invention is a highly energy-efficient way of dimming a normally "non-dimmable" lighting system. The dimming device has also been tested successfully to dim two sets of 2x36W T8 fluorescent lamps driven by two conventional magnetic ballasts from 100% to about 40% of full lamp
25 power. Fig.11(a) and Fig.11(b) shows the measurements of the total lamp power in a 2X36W T8 lamp system (one lamp is a Philips TLD 36W/33 Cool White and the other lamp is TLD 36W/54 Day Light) powered by a Philips magnetic ballast and the 2X36W lamp system is dimmed by the proposed dimmer. At full load, the lamp system consumes about 70W. Within the dimming range from 100% to 40% (30W) of the full power, the
30 total loss in the dimmer is less than 2W.

In the embodiments described above no separate energy source is required for the generation of the auxiliary voltage. However, if desired an auxiliary energy source could be used as illustrated in Fig.13. If the auxiliary energy source is an AC voltage, then an AC-AC power converter can be used to generate V_x . If the auxiliary energy source is a DC voltage, then a DC-AC power converter (such as the half-bridge power inverter or full-bridge power inverter) can be used to produce V_x .

The invention can also be applied to certain electronic ballasts for discharge lamps provided that the electronic ballasts are of a type that can be dimmed by reducing the ac input voltage to the ballasts.

CLAIMS

1. Apparatus for providing dimming control of an electrical lamp of the type driven by a ballast that is provided between an AC supply and the lamp, comprising means located in series between the AC supply and the ballast for inserting an auxiliary voltage, said auxiliary voltage being out of phase with said AC supply, whereby the supply voltage is the vectorial combination of the voltage applied to the ballast and the auxiliary voltage, such that the magnitude of the voltage applied to the ballast is smaller than the magnitude of the voltage of the AC supply, and further comprising means for controlling the auxiliary voltage for varying the voltage applied to the lamp.
2. Apparatus as claimed in claim 1 wherein the phase of the auxiliary voltage is maintained 90 or 270 degrees out of phase with the current flowing through said apparatus, and wherein the magnitude of the auxiliary voltage is used for varying the voltage applied to the lamp.
3. Apparatus as claimed in claim 1 including a power converter for generating said auxiliary voltage.
4. Apparatus as claimed in claim 3 wherein said power converter comprises a half-bridge inverter including two switches that are switched at high-frequency to generate a pulse-width-modulated (PWM) waveform as an output.
5. Apparatus as claimed in claim 4 wherein the PWM output of said half-bridge inverter is filtered to provide said auxiliary voltage.
6. Apparatus as claimed in claim 4 wherein means are provided to select a desired the DC link voltage for the half-bridge inverter in order to control the magnitude of the auxiliary voltage.

7. Apparatus as claimed in claim 6 wherein means are provided to maintain said DC link voltage at said desired value and to maintain the phase of said auxiliary voltage 90 or 270 degrees out of phase with the current flowing through said apparatus.
8. Apparatus as claimed in claim 7 wherein a closed loop control scheme is used for maintaining said DC link voltage at said desired value and for maintaining the phase of said auxiliary voltage 90 or 270 degrees out of phase with said current.
9. Apparatus as claimed in claim 3 wherein said power converter is a full-bridge converter.
10. Apparatus as claimed in claim 1 wherein said apparatus further includes switch means whereby said apparatus may be by-passed if dimming control is not required and the voltage of the AC supply is applied directly to the ballast.
11. An electrical lighting system comprising at least one lamp connected to an AC supply through a ballast, said system further comprising means for providing dimming control of said at least one lamp, said dimming control means comprising means located in series between the AC supply and the ballast for inserting an auxiliary voltage, said auxiliary voltage being out of phase with said AC supply, whereby the supply voltage is the vectorial combination of the voltage applied to the ballast and the auxiliary voltage, whereby the voltage applied to the ballast has a magnitude that is smaller than the magnitude of the voltage of the AC supply, and further comprising means for controlling the auxiliary voltage for varying the voltage applied to the lamp.
12. A system as claimed in claim 11 wherein the auxiliary voltage is maintained at 90 or 270 degrees out of phase with the current flowing through said

dimming control means, and wherein the magnitude of the auxiliary voltage is used for varying the voltage applied to the lamp.

5 13. A system as claimed in claim 11 wherein said dimming control means comprises a power converter for generating said auxiliary voltage.

10 14. A system as claimed in claim 13 wherein said power converter comprises a half-bridge inverter including two switches that are switched at high-frequency to generate a pulse-width-modulated (PWM) waveform as an output.

15 15. A system as claimed in claim 14 wherein the PWM output of said half-bridge inverter is filtered to provide said auxiliary voltage.

16 16. A system as claimed in claim 14 wherein means are provided to select a desired DC link voltage for the half-bridge inverter in order to control the magnitude of the auxiliary voltage.

20 17. A system as claimed in claim 16 wherein means are provided to maintain said DC link voltage at said desired value and to maintain the phase of said auxiliary voltage 90 or 270 degrees out of phase with the current flowing through said dimming control means.

25 18. A system as claimed in claim 17 wherein a closed loop control scheme is used for maintaining said DC link voltage at said desired value and for maintaining the phase of said auxiliary voltage 90 or 270 degrees out of phase with said current.

30 19. A system as claimed in claim 13 wherein said power converter comprises a full-bridge inverter.

20. A system as claimed in claim 11 further comprising switch means whereby said dimming control means may be by-passed if dimming control is not required and the voltage of the AC supply is applied directly to the ballast.
- 5 21. A system as claimed in claim 11 wherein said ballast is a magnetic ballast.
22. A system as claimed in claim 11 wherein said ballast is an electronic ballast of the type that enables a light to be dimmed by reduction of the AC input voltage to the ballast.
- 10 23. A system as claimed in claim 11 including a plurality of lamps.
24. A method for providing dimming control of an electrical lamp driven by a ballast, comprising inserting an auxiliary voltage between an AC supply and said ballast, said auxiliary voltage being out of phase with the voltage of said AC supply whereby the supply voltage is the vectorial combination of the voltage applied to the ballast and the auxiliary voltage.
- 15 25. A method as claimed in claim 24 wherein the auxiliary voltage is maintained 90 or 270 degrees out of phase with the current supplied to the ballast.
- 20 26. A method as claimed in claim 24 wherein the auxiliary voltage is generated by a power converter.
- 25 27. A method as claimed in claim 26 wherein said power converter comprises a half-bridge inverter including two switches that are switched at high frequency to generate a pulse-width-modulated (PWM) waveform as an output.
- 30 28. A method as claimed in claim 27 further including filtering the output of the half-bridge inverter to produce said auxiliary voltage.

29. A method as claimed in claim 27 wherein the magnitude of the auxiliary voltage is controlled by setting the DC link voltage of the half-bridge inverter.
- 5 30. A method as claimed in claim 29 wherein control means are provided for maintaining the magnitude of the DC link voltage and for maintaining the auxiliary voltage 90 or 270 degrees out of phase with the current supplied to the ballast.
- 10 31. A method as claimed in claim 26 wherein the power converter is a full-bridge converter.

ABSTRACT

5

APPARATUS AND METHOD FOR PROVIDING DIMMING
CONTROL OF LAMPS AND ELECTRICAL LIGHTING SYSTEMS

There is disclosed an energy-saving dimming method and apparatus that can be
10 used to convert a wide range of existing "non-dimmable" electric lighting products and
systems into "dimmable" ones. Examples of non-dimmable electric lighting systems are
(i) high-pressure and low-pressure discharge lamps powered either by magnetic ballasts
or by some electronic ballasts, (ii) incandescent lamps and (iii) a group of electric
lighting systems. Based on a new integrated approach of a voltage-vector control and
15 reactive-power control concept, the voltage applied to the lighting systems can be varied
smoothly without handling the real-power of the lighting system. Consequently, the
proposed dimming device and method can be used as a general-purpose, energy-saving
dimming approach to the dimming of a wide range of "non-dimmable" electric lighting
systems. By inserting a voltage vector through an energy-efficient switched-mode
20 reactive-power-control circuit, the resultant voltage can be controlled and varied as a
variable and controllable voltage source for dimming many electric lighting systems such
as existing magnetic ballast driven gaseous discharge lamps systems and incandescent
lamps.

$\frac{1}{n}$

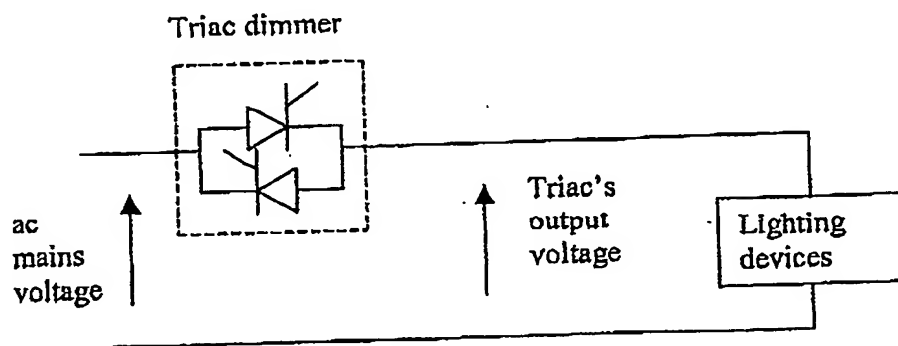


FIG.1(a)

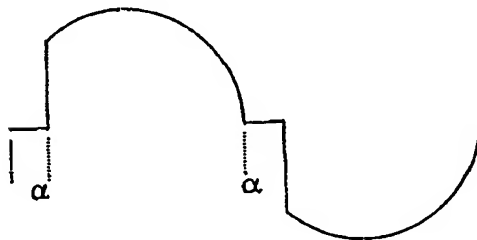


FIG.1(b)

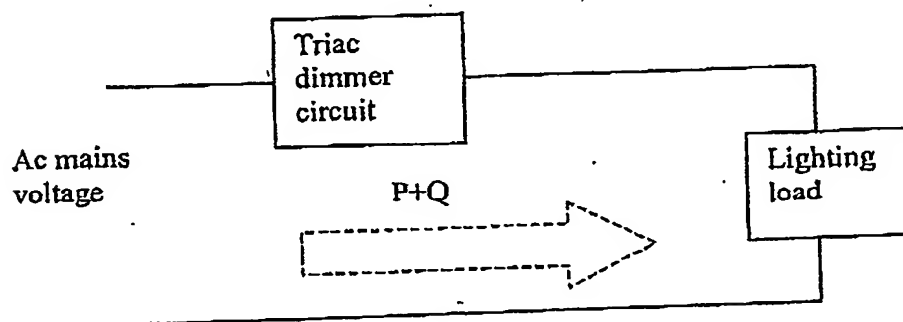


FIG.1(c)

2/11

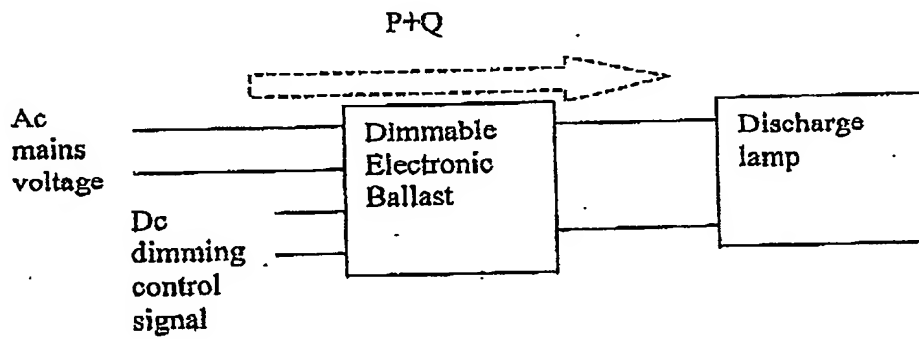


FIG. 2

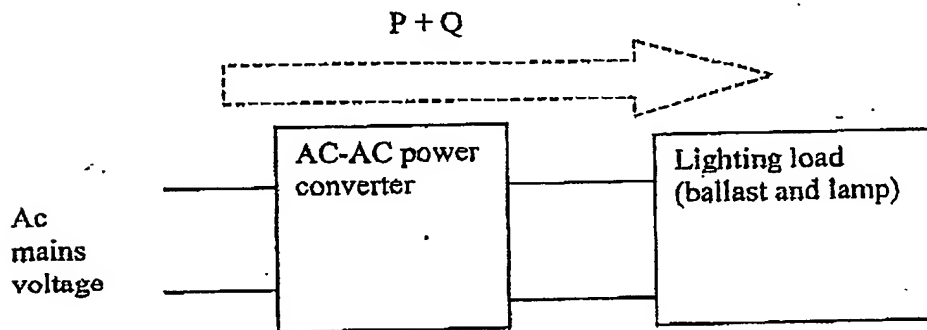


FIG. 3

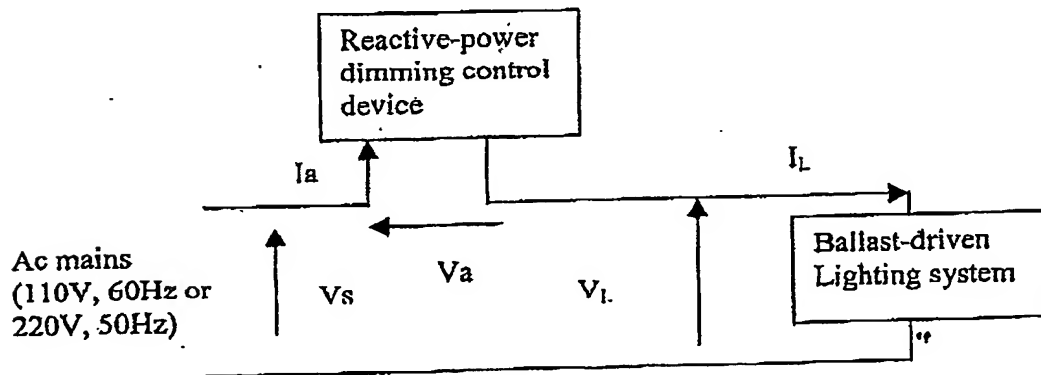


FIG. 4(a)

3/11

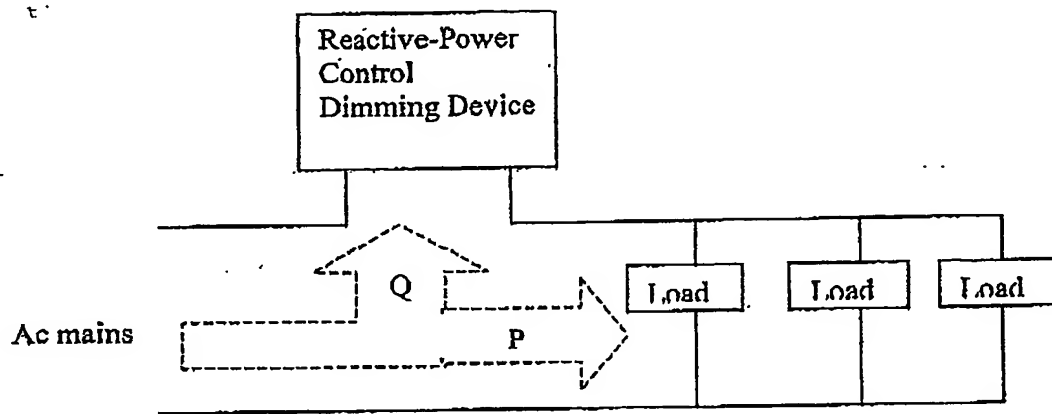


FIG.4(b)

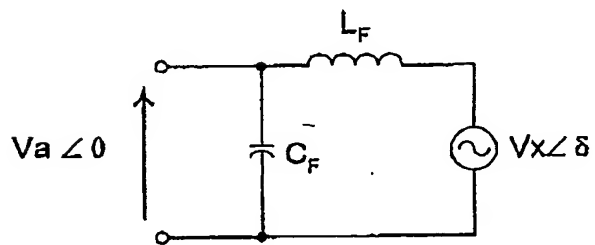


FIG.4(c)

4/11

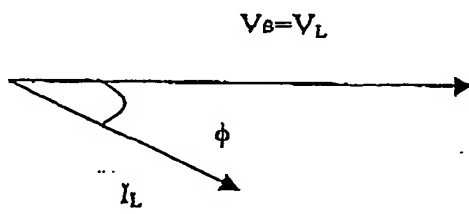


FIG. 5(a)

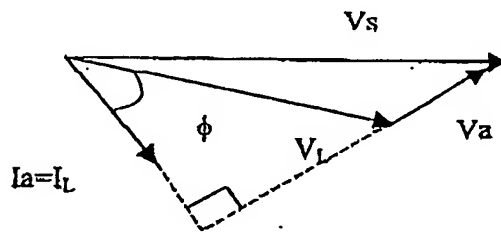


FIG. 5(b)

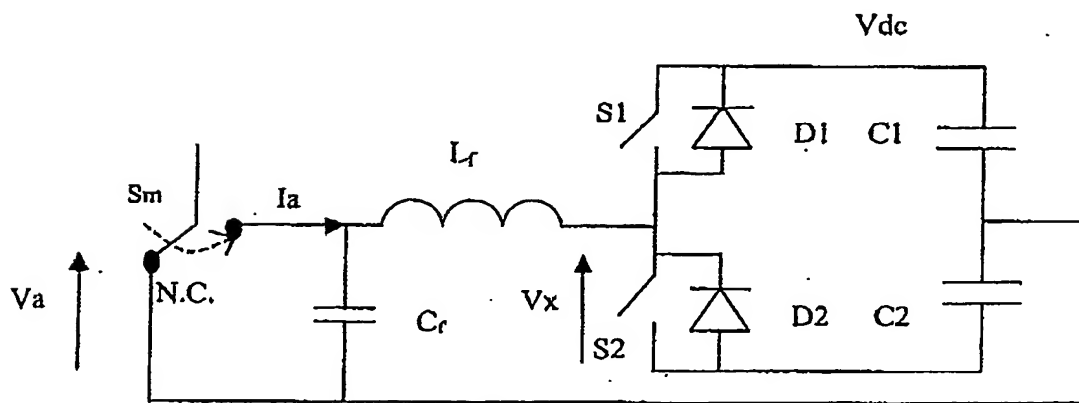
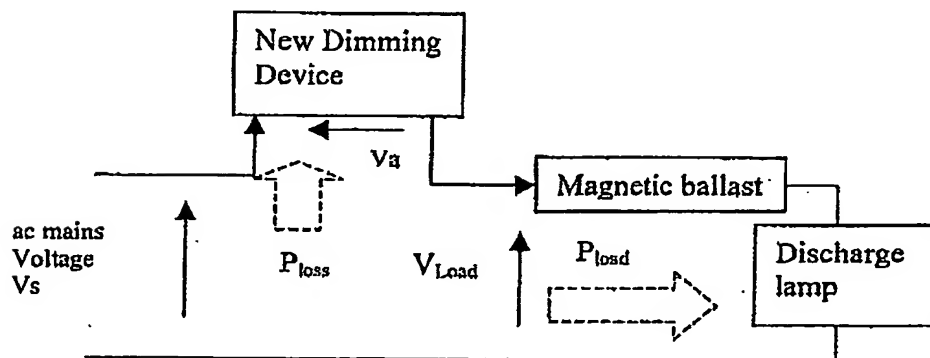
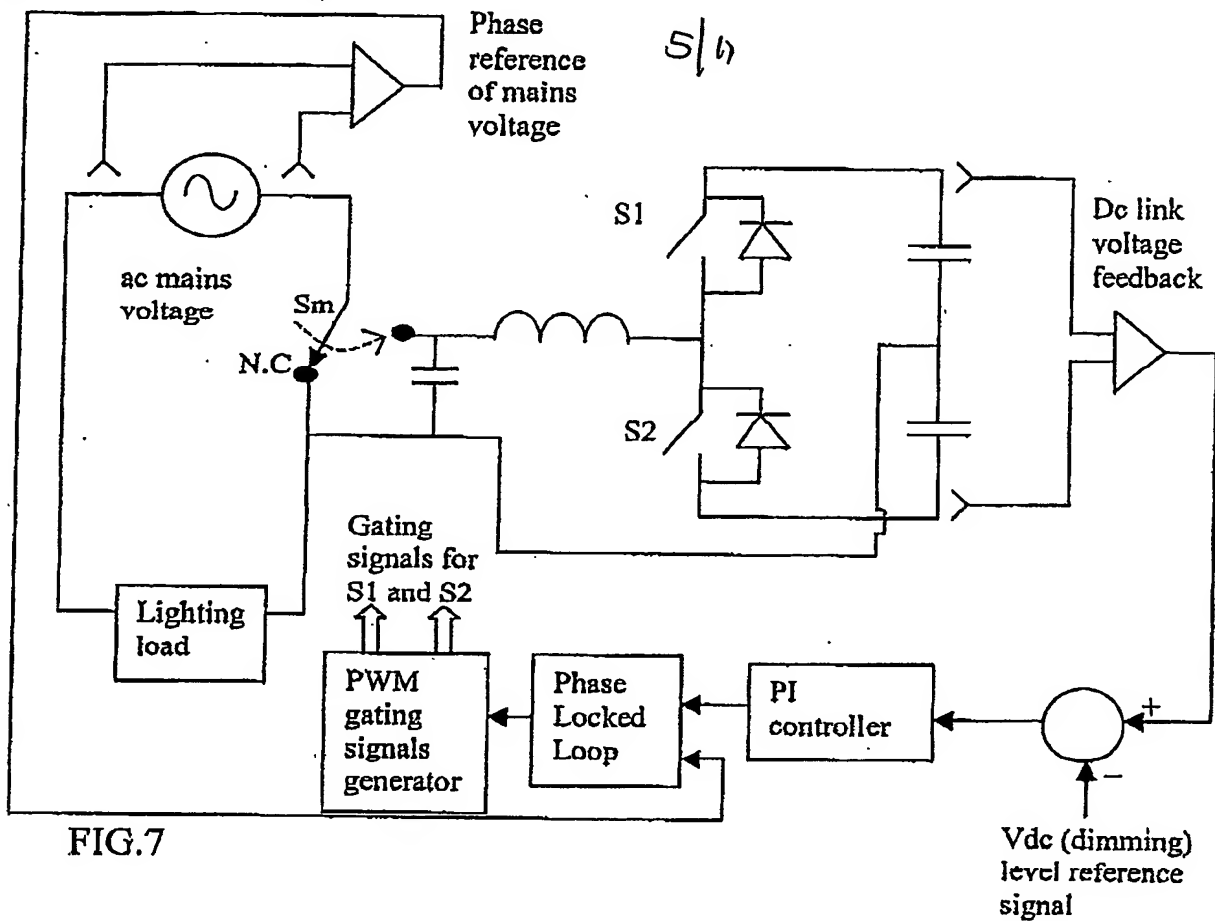


FIG. 6



6/13

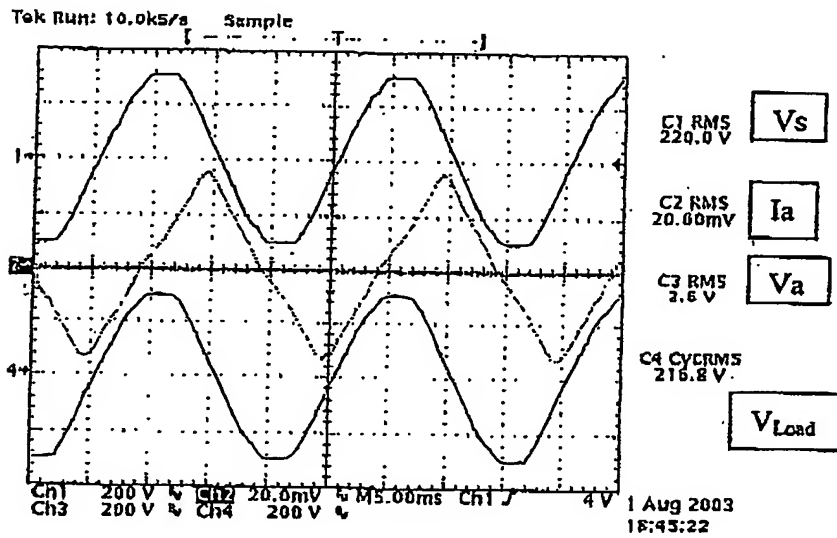


FIG.9(a)

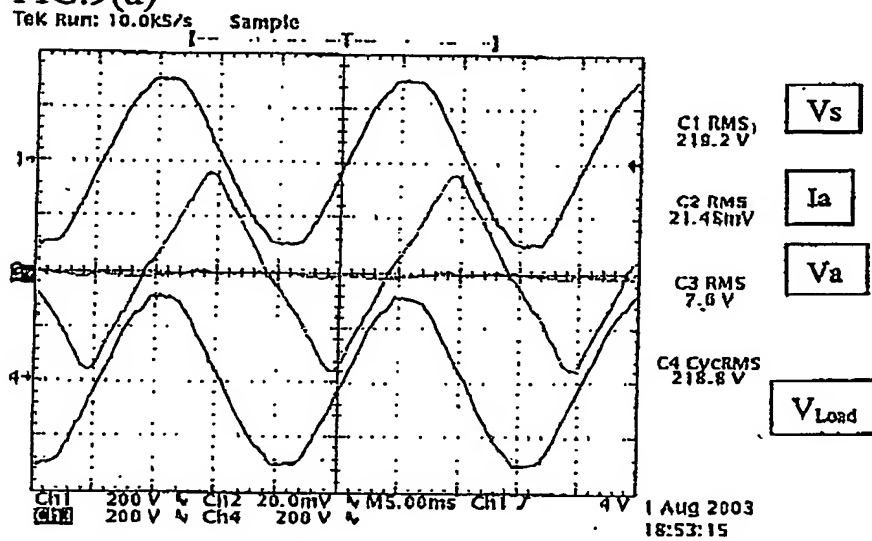


FIG.9(b)

7/11

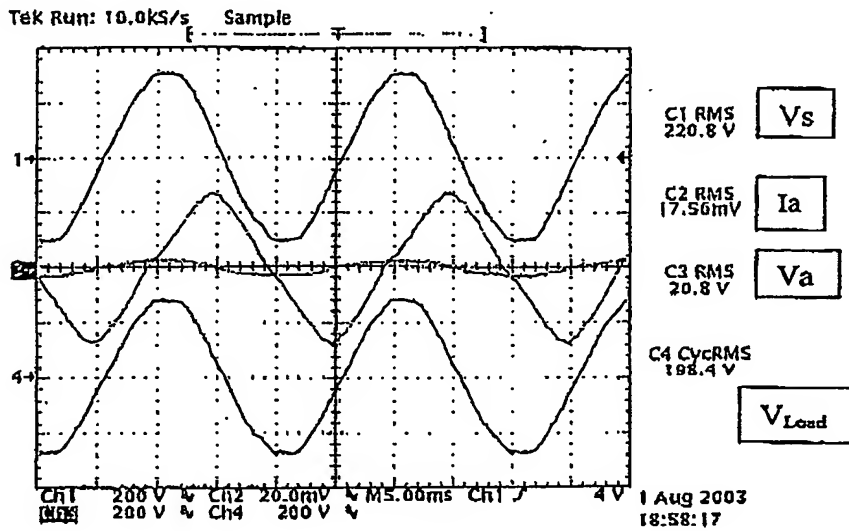


FIG.9(c)

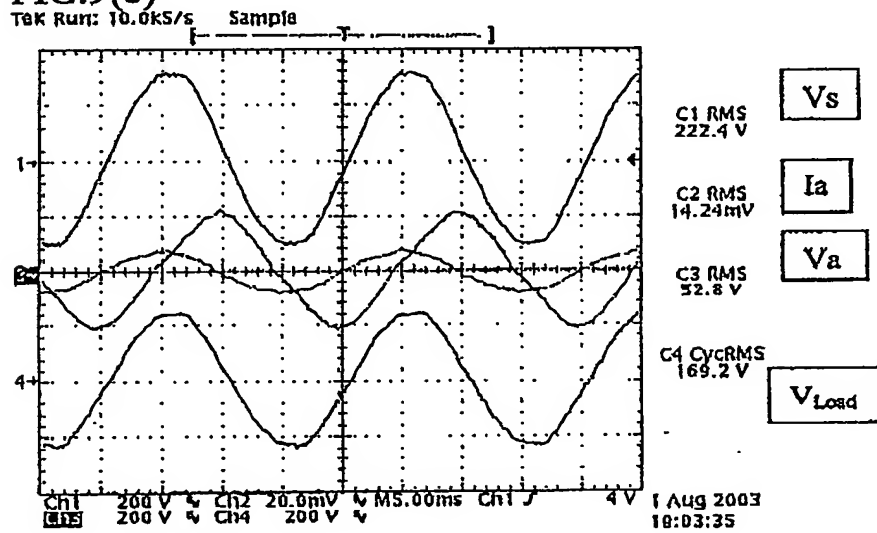


FIG.9(d)

8/11

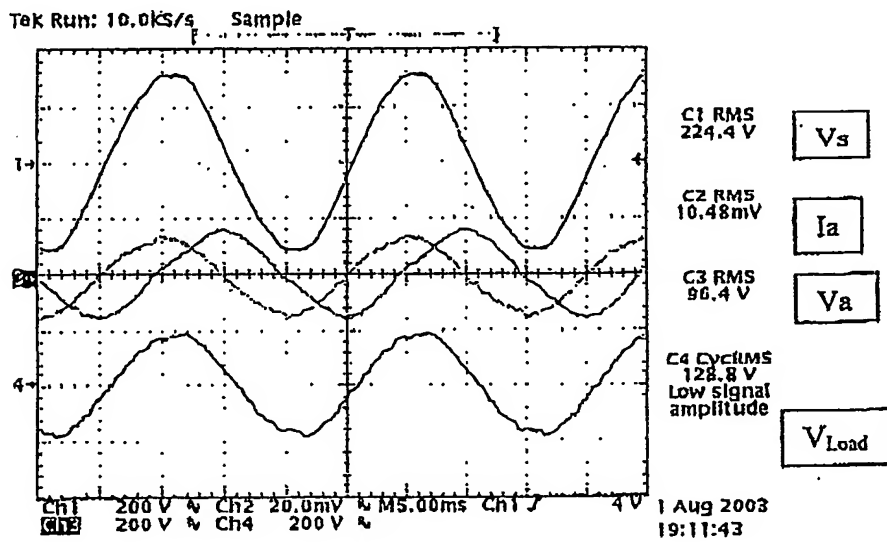


FIG.9(e)

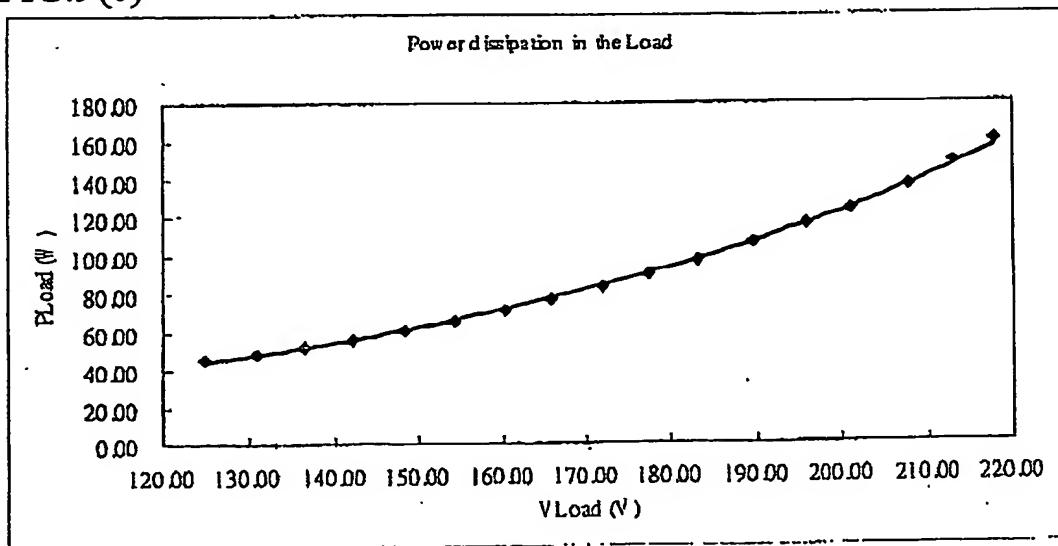


FIG.9(f)

9/11

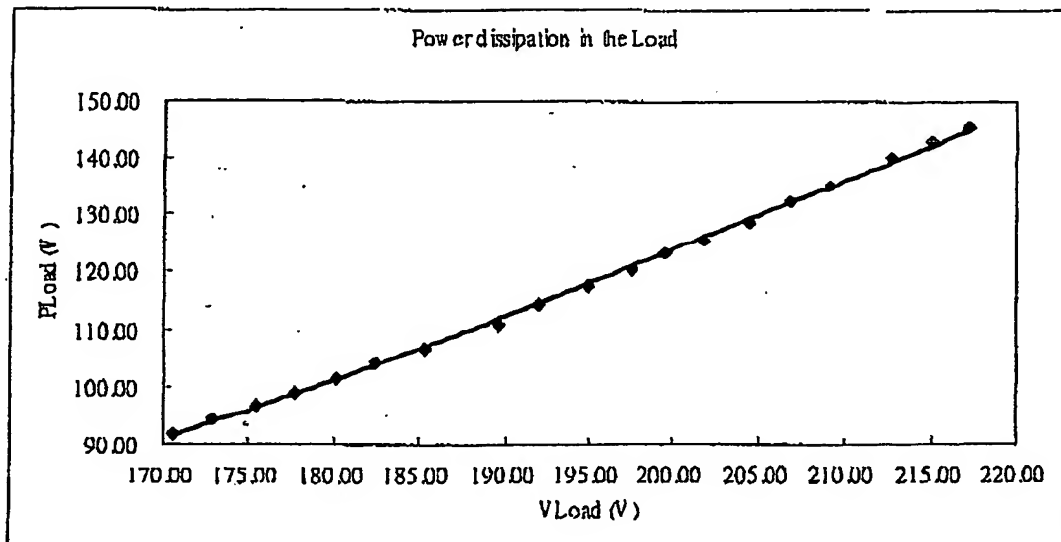


FIG.10(a)

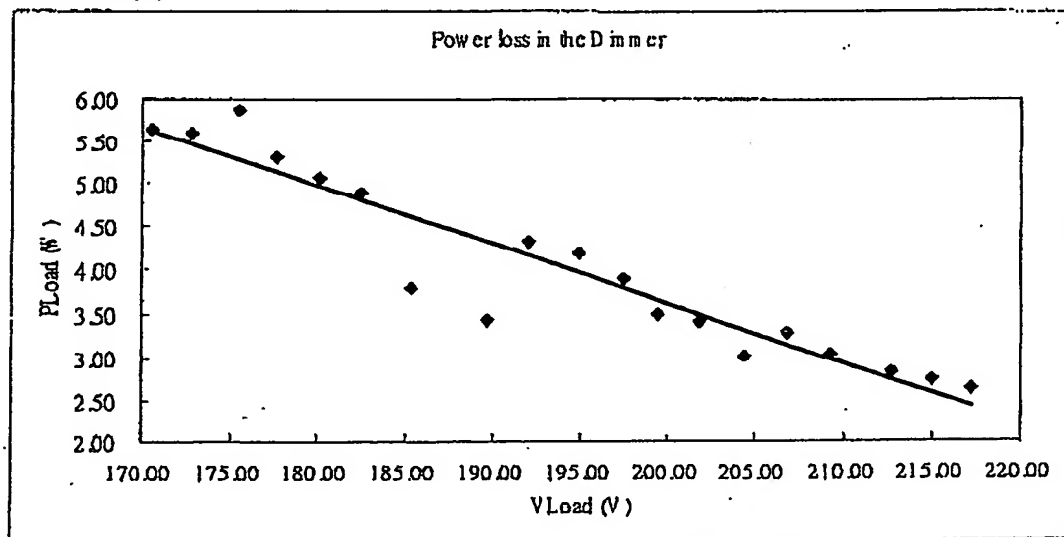


FIG.10(b)

10/11

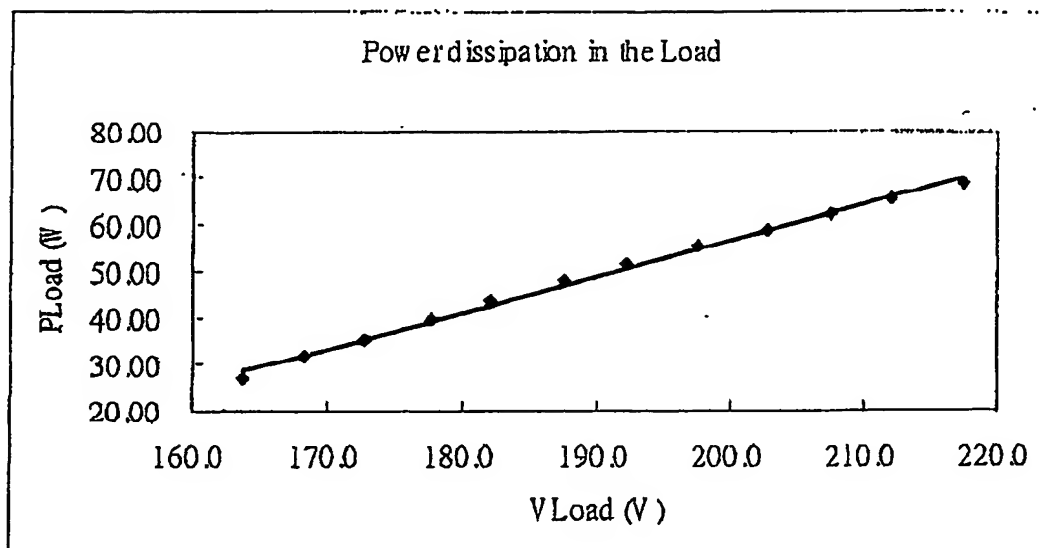


FIG.11(a)

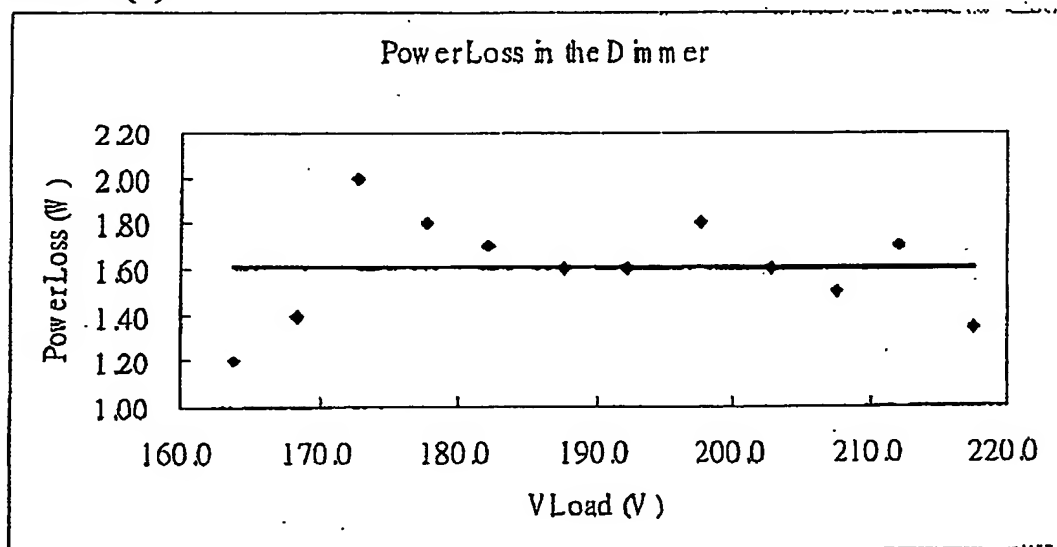


FIG.11(b)

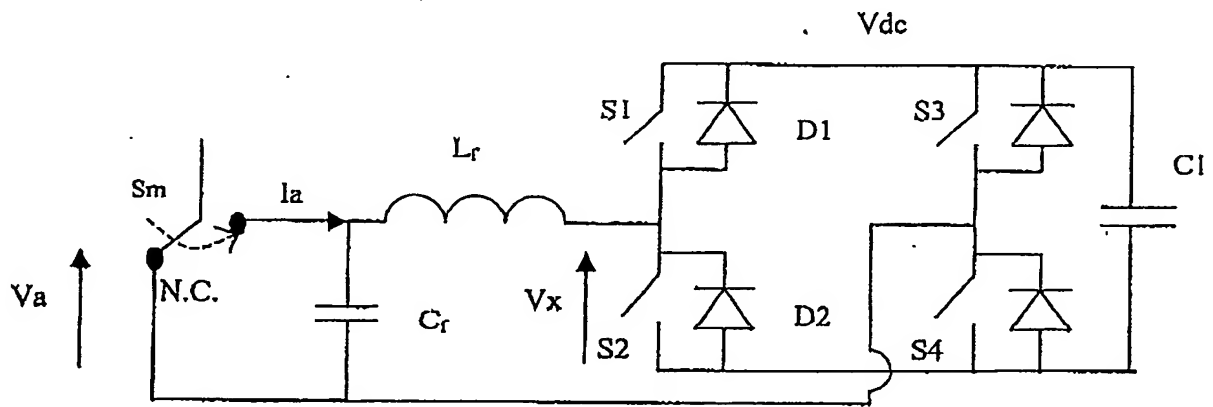


FIG. 12

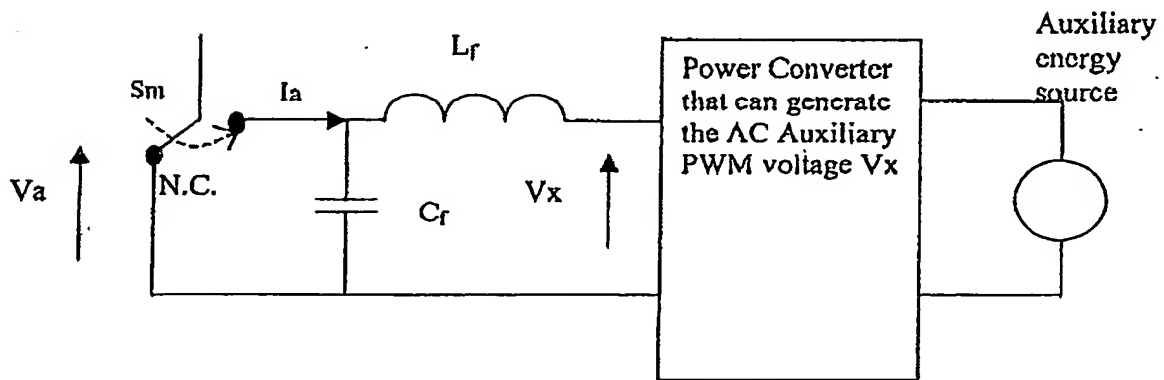


FIG. 13

PCT/CN2004/000990



**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☒ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☒ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.